



Fermilab
ES&H Section

**CALCULATIONS AND MEASUREMENTS OF
 ^3H CONCENTRATIONS AT FERMILAB**

Alex Elwyn
May 22, 1997

Written by: Alex Elwyn
Alex Elwyn

Date: 5/29/97

Reviewed by: Don Cossairt
Don Cossairt, RP Group Associate Head

Date: 5/29/97

Reviewed by: Rod Walton
Rod Walton, EP Group Associate Head

Date: 5/30/97

Approved by: William J. Griffing
William Griffing, ES&H Section Head

Date: 6/3/97

Distribution via Quick mail (approved version on file):
R.P. Staff, EP Staff, D. Cossairt

CALCULATIONS AND MEASUREMENTS OF ^3H CONCENTRATIONS AT FERMILAB

Alex Elwyn

May 22, 1997

I. Calculations

Protons accelerated in the Tevatron along with secondary particles produced through their interactions can generate hadronic cascades within beam absorbers at targeting areas (sources), and those particles which leak through the shielding can activate the surrounding material. At Fermilab the Monte Carlo computer program CASIM (Va75a, Va75b) is used to simulate this process through the inclusion of particular hadron production processes by modeling the geometry of the source. The program then computes nuclear interaction densities (so called star densities, in units of stars/cm³-incident proton) as a function of location throughout the materials surrounding the interaction region. Calculations of external dose equivalent outside of shielding based on CASIM, have been found to compare within factors of two or three with measured doses for a wide variety of beam loss and shielding geometry conditions (see, e.g., Aw76, Co85). In connection with the possible activation of ground water, however, CASIM calculations have traditionally been used only in the design of the shielding necessary to allow a given annual number of protons to be delivered to a source area without the radioactivation exceeding Federal and State drinking water (ground water) regulations. These estimates have in the past been based on a very conservative model (the SRWM) (see, e.g., Go78) that details how the activation gets into the drinking water. With the development of the so called Concentration Model (Ma93), on the other hand, it has become possible to calculate the concentration of radioisotopes in the soil directly below the source enclosure, and from knowledge of leaching by water, to convert this into a concentration in the water in the ground. This initial concentration is then directly comparable with surface water regulations. It should be kept in mind that the surface water discharge limit for ^3H is 2000 pCi/ml, a factor of 100 times larger than the drinking water (ground water) limit. From reduction factors calculated by Woodward-Clyde Consultants (Wc93) as a function of distance within the glacial till from the source to the aquifer, the initial concentrations can be transformed into final concentrations in the aquifer. These can be compared with ground water regulations which limit the ^3H concentration to 20 pCi/ml.

The aim of the present work is to compare the calculated concentration of the radionuclide ^3H in the water in the soil just outside of well-shielded source areas at Fermilab with measurements of ^3H concentrations in, for example, nearby monitored sump and retention pit water. The initial concentration in any given year is calculated with the parameter values suggested by Cossairt (Co94) from a modified form of the expression given by Malensek, et al (Ma93).

The expression given by Malensek, et al includes a factor to account for long term build-up of activation to its saturation value. This does not seem appropriate for the situation in which comparison of a yearly accumulation of activity is made with measured concentrations for that year. Accordingly the saturation build-up factor, which for ^3H is 17.7, is deleted from the expression on page 23 of TM-1851 (Ma93) for the purposes of the present work. In the tables shown in Sect. III for the different source locations the last column represents the calculated cumulative concentrations for the given year, starting from the first year listed in each table, corrected for the decay of ^3H .

II. Measurements

While Fermilab has a wide and diversified monitoring program in which water samples from nearby wells, sump holes, retention pits, and in some cases soil samples from regions near sources and loss points are collected, there have been few, if any, direct measurements, or even any direct sampling, of radioisotope concentrations at exactly the same locations simulated by the CASIM calculations. Therefore, in the present report comparison is made to ^3H concentrations deduced from the cumulative record of analyses of water collected over time from sampling locations in the general source vicinity, and from underdrains whose effluent is released as surface water discharge, and in a few instances, from soil borings. At some source areas, notably D0 when that area was used as the Main Ring abort (1972-1982), the soil activation was monitored by a system of Al and Cu tags (foils) placed inside the Main Ring tunnel (Ba85). These were changed periodically and the radioactivity in the tags assayed, mostly for ^{22}Na . Previously, the relationship between the concentration of ^{22}Na in Al foils and in cans of activated soil, sand, and gravel had been determined, so that simply monitoring the tags became a convenient way for measuring the distribution of a particular radionuclide near a loss point. According to Baker (Ba75): "Predictions of peak concentrations in the soil outside the tunnels or enclosures based on tag and soil can results inside the enclosures, and Monte Carlo extrapolations of the cascade into the soil shielding, have generally been reliable." Further, early verification of the agreement between such measurements with calculations at the neutrino targeting area are documented by Moore and Baker (Mo77).

There are perhaps eight source, or loss point, areas in the accelerator ring complex, and fourteen more in the experimental beamline areas. One problem in the comparison of ^3H concentrations based on calculations at a specific source location with water sampling results is that the sump holes and retention pits that are monitored may actually collect radioactive water from a number of sources simultaneously because many of the sources are so close to each other. In fact, in a number of cases the targeting stations are in the same enclosures. Comparisons shown in this report are, therefore, in many cases, of a global nature rather than with a specific source calculation.

H concentrations are proportional to the total number of protons incident on the source targets. Table 1 displays the number of protons delivered annually to the various experimental beam lines from 1984-1985, the start of the 800-900 GeV Tevatron era, through 1996. The operating history of the accelerator since 1984 is shown in Table 2. Because documentation of pre-Tevatron era records is so scattered and not easily obtainable, comparisons are for the most part between calculations and sampling results during the period after 1984.

**Table 1: Total number of protons ($\times 10^{16}$) sent to the various experimental area beam lines from the start of the 800-900 GeV Tevatron era.
(The 1984 numbers are uncertain).**

	1984	1985	1987	1988	1990	1991	1996
MW/MT	.76		6.80	6.60	30.0	12.1	.30
MC	1.70	7.50	7.70	2.10	2.12	20.8	8.12
MP			4.90	4.70	18.0		
ME	2.41	17.3	4.50	5.00	.72	.74	8.98
NW	1.36				25.2	10.5	
NC	1.54	63.7	52.8	11.6			110.0
NE/NT	1.11	13.5	7.70	2.30	6.26	2.73	3.57
NM/KTEV			17.6	7.10	35.3	54.0	15.9
PW	.27 (?)	7.90	4.50	2.80	2.10	1.45	2.31
PC	1.66	2.90	1.40	1.65	7.29	16.8	3.63
PE	1.11	17.3	6.90	2.70	10.7	27.8	
PB			6.40	6.40	36.2	38.2	37.3

Table 2: Operating history of the accelerator from the start of the Tevatron Era to the present.

START DATE	END DATE	OPERATING MODE
27-Sep-83	17-Feb-84	400 GeV fixed target
12-Mar-84	16-Jul-84	800 GeV fixed target
14-Jan-85	29-Aug-85	800 GeV fixed target
13-Sep-85	14-Oct-85	800 GeV collider
2-Feb-87	11-May-87	900 GeV collider
15-Jun-87	15-Feb-88	800 GeV fixed target
20-Jun-88	31-May-89	900 GeV collider
12-Feb-90	27-Aug-90	800 GeV fixed target
16-Jul-91	08-Jan-92	800 GeV fixed target
31-Aug-92	01-Jun-93	900 GeV collider
15-Dec-93	19-Feb-96	900 GeV collider
01-Aug-96	present	800 GeV fixed target

III. Sources

A. Neutrino Area

1. **NC:** From 1972-1982, the neutrino area primary target was inside a steel tube in an enclosure that was then called NeuHall. During this period the proton beam was accelerated to energies up to 400 GeV and over half of the total protons extracted from the accelerator, about 10^{20} protons, were incident on this target. The only calculation available from that early era is Awschalom (Aw72) and it does not use CASIM, but FLUTRA (see Aw72). Furthermore, no star densities are given; there is only an estimate of the total stars in a given region. Thus, it is not possible to determine a ^3H concentration in the region just below the source. The sump and retention pit monitoring data during this time period is not easily obtainable as it exists, for the most part, in handwritten reports and notebooks.

Soil borings were made in 1975 (Ba75), 1984 (Ba85, Co90), and 1988 (Co90). The purpose of the 1975 boring was to search within the "bathtub" for any ^3H and ^{22}Na . Concentrations of both nuclides were observed. It should be noted that the water from the bathtub is drained by an inner drain into a retention pit which is sampled periodically; in pre-Tevatron days this water was collected and evaporated when the peak ^3H concentration reached 1000 pCi/ml. In 1984, a hole was drilled into the berm at an angle of 45° in order to sample the lowest underdrains below the bathtub. The maximum concentration found was 10.8 pCi/ml of ^3H evaporated from a soil sample taken from just within the region activated by the secondary particles from the beam. Below this region the concentration was less than 1 pCi/ml indicating that there is little evidence for radionuclides heading for the aquifer. At the same time the maximum concentration in the sump receiving water from the underdrains (in 1984) was 250 pCi/ml. The sampling holes drilled in 1988 confirm that only low level concentrations of radionuclides exist below the underdrains, except in one case and this concentration is thought to arise from contamination due to the drilling process itself (Co90).

After 1982, targeting was in N01. A CASIM calculation by Couch (Co82) which includes a bathtub surrounding protected soil, gave a maximum star density of about 8×10^{-10} stars/cm³-p in the unprotected region. However, on the assumption of no protected soil region, $S_{\text{max}} = 8 \times 10^{-7}$ stars/cm³-p. This leads to a ^3H concentration (modified as discussed in Sect. I) of 8.14×10^{-17} pCi/ml-p. It should be noted that before the actual running period with this target the CASIM model was refined, reflecting minor changes in the beam absorber and target geometry, but documentation is not available to show possible changes to the star density. This beam was run from 1985-March 1988. The sumps and retention pits that are monitored are N01SP1, N01SP2, N01SP3, N01SP4, N01RP1 and N01RP2. Table 3 shows a comparison of maximum sampled ^3H concentrations with those calculated.

Table 3: Comparison of calculated and sampled maximum ^3H concentrations for N01.

YEAR	$C_i(\text{MAX})$ (pCi/ml)	LOCATION	PROTONS/YR ($\times 10^{17}$)	$C_i(\text{CALC})$ (pCi/ml)
1985	446.1	N01RP2	6.37	51.8
1986	6973	N01RP2		48.9
1987	635	N01RP2	5.28	89.2
1988	355	N01RP2	1.16	93.7
1989	476	N01RP2		88.6
1990	361	N01RP2		83.7
1991	276	N01RP2		79.1
1996	149	N01RP2	11.0	164.3

The yearly concentrations predicted by the CASIM calculations are for the most part lower than the maximum monitored concentrations for that year. However, it should be noted that retention pit water generally comes from the drains within the bathtub, and that region was considered as protected when this target area was designed. In 1996, the calculated concentration agrees with that sampled. The very high 1986 number probably reflects a spill of a closed loop cooling water system rather than the production of ^3H from soil activation, although the evidence for this is not definite.

2. **NE/NT:** This beamline configuration ran during fixed target runs from 1985 to 1991. A calculation was made in 1980 (Co80). From contour plots for the 1000 GeV calculation $S_{\text{max}} = 8 \times 10^{-7}$ stars/cm³. This leads to a ^3H concentration of 8.13×10^{-17} pCi/ml-p. The closest sampling location is NE8SP1, which in 1985/86 gave a maximum concentration of 27 pCi/ml. Sampling at this location was discontinued in 1987. Calculated cumulative concentrations are shown in Table 4.

Table 4: Comparison of calculated and sampled maximum ^3H concentrations for NE/NT.

YEAR	$C_i(\text{MAX})$ (pCi/ml)	LOCATION	PROTONS/YR ($\times 10^{17}$)	$C_i(\text{CALC})$ (pCi/ml)
1985	27	NE8SP1	1.35	11.0
1986	0	NE8SP1		10.4
1987			.77	16.0
1988			.23	17.0
1989				16.1
1990			.626	20.3
1991			.273	21.4
1996			.357	23.1

3. **NM:** The muon beam ran for the first time in 1987/88, and then again in 1990/91. A calculation was performed by Butala/Malensek (Bu83a) but no star density contours are shown. However, another memo from Butala (Bu83b) compared NM and PB shielding, and from contour plots a value of $S_{\max} = 8 \times 10^{-8}$ stars/cm³-p is observed, on the assumption of no protected soil region. This gives a ³H concentration of 8.14×10^{-18} pCi/ml-p. Sampling locations are NM1SP1, NM2SP2, NM2SP3, NM2RP, NM3, NMK. The maximum sampled concentrations were observed in the water from NM2RP. It should be noted that this retention pit also received water from the floor drains in Neu hall, and so the concentrations shown below may not be associated with the NM2 targeting at all. In fact, for the years during which the NM beam line was running, the ³H concentrations observed in water from NM2SP2, located right next to the NM2RP retention pit, are all less than 5 pCi/ml. The results for NM are shown in Table 5.

Table 5: Comparison of calculated and sampled maximum ³H concentrations for NM.

YEAR	C _i (MAX) (pCi/ml)	LOCATION	PROTONS/YR ($\times 10^{17}$)	C _i (CALC) (pCi/ml)
1987	9.2	NM2RP	1.76	1.4
1988	74	NM2RP	.71	1.9
1989	102	NM2RP		1.8
1990	45.5	NM2RP	3.53	4.6
1991	221.9	NM2RP	5.40	8.7
1996	3.92	NM2RP	1.59	9.6

4. **NW:** A calculation was done by Koizumi (Ko91) for the target in NW3 (target manhole). Unfortunately, no star density contours are shown so it is not possible to estimate the maximum star density outside of the target and beam absorber pipe. This target apparently lies within the bathtub associated with the old target tube (Neu hall), and the bathtub is assumed to protect the soil out to about 5 feet away from the pipe. In addition to the monitoring/sampling locations associated with the other target areas in the N01 enclosure, location NW8SP3 is more explicitly associated with NW beamline. Only in 1995 did a ³H concentration (2.5 pCi/ml) exceed the sensitivity of the analysis of any samples taken between 1985 and 1996.

B. Proton Area

1. **PE:** The PE target box in Enclosure PE3 was modeled by Baker (Ba76). In the report Baker discusses how measurements of activation in Cu and Al tags were converted into ²²Na activity in soil. The calculation although not directly based on CASIM did use some of the results from Va75a, and was found to agree (within a factor of two) with a calculation based on a very early version of CASIM. From the equivalent steel block model of the target and concrete floor used by Baker (and shown in the report), star densities can be estimated by use of Figs. VIII.3 and VIII.4

of Van Ginneken and Awschalom (Va75a). For 800 GeV Tevatron running, $S_{\max} = 4.4 \times 10^{-8}$ stars/cm³-p in the soil directly below the enclosure. This corresponds to a ³H concentration of 4.46×10^{-18} pCi/ml-p. PE3SP2 is the appropriate sampling location for the PE target box. Table 6 compares the maximum annual sampled concentrations with those calculated. It should be noted, however, that since the PE target box has been in use since the early 1970s many more protons, mostly with energies of 400 GeV and below, have actually been targeted at this location. In any event, except in 1986 (when there were no protons targeted) the maximum calculated concentrations are equal within factors of two or three to those measured.

Table 6: Comparison of calculated and sampled maximum ³H concentrations for PE.

YEAR	C _i (MAX) (pCi/ml)	LOCATION	PROTON/YR ($\times 10^{17}$)	C _i (CALC) (pCi/ml)
1985	3	PE3SP2	1.73	0.77
1986	18.4	PE3SP2		0.73
1987	3	PE3SP2	.69	1.00
1988	3	PE3SP2	.27	1.07
1989	<3	PE3SP2		1.01
1990	3.4	PE3SP2	1.07	1.43
1991	2.1	PE3SP2	2.78	2.60
1996	2.3	PE3SP2		2.45

2. **PB:** The original CASIM calculation was done by Gerardi (Ge83). The calculation was recently updated by W. Miller (Mi96). From this update $S_{\max} = 1.9 \times 10^{-7}$ stars/cm³-p, and the ³H concentration is 1.93×10^{-17} pCi/ml-p. The PB target pile is in the PE4 beam enclosure; the sampling location is the PE4Hole (now called PB4TGTSH1). This hole was put in when the PB beam line was first run (in 1987) and was last sampled in 1988, when it was found to be dry. There does not, therefore, seem to be any sampling record for this enclosure. The maximum calculated ³H concentrations are shown in Table 7.

Table 7: Calculated maximum ³H concentrations for PB.

YEAR	PROTONS/YR ($\times 10^{17}$)	C _i (CALC) (pCi/ml)
1987	.64	1.2
1988	.64	2.4
1989		2.3
1990	3.62	9.1
1991	3.82	16.0
1996	3.73	22.3

3. **PC:** An early CASIM calculation by Cossairt (Co79; see also Co94) gives 1.5×10^{-8} stars/cm³-p in the soil right outside of the enclosure. A recent calculation (Zi96) suggests a value about three times larger, 4.89×10^{-8} stars/cm³-p. With this latter value, the ³H concentration outside of the enclosure is 5.0×10^{-18} pCi/ml-p. The monitoring locations appropriate to the PC target are PC4SP1 and PC4SP2. Concentrations calculated and sampled are shown in Table 8. An investigation (see Fr92) into the 1991 reported value of 91.4 pCi/ml, which represented a rather large increase in the output from PC4SP2, was not able to completely resolve the causes for this increase, although other sources, notably PE3, are in the vicinity, and could contribute. In any event, the reported value is well below the surface water discharge limit of 2000 pCi/ml.

Table 8: Comparison of calculated and sampled maximum ³H concentrations for PC.

YEAR	C _i (MAX) (pCi/ml)	LOCATION	PROTON/YR ($\times 10^{17}$)	C _i (CALC) (pCi/ml)
1985	<3	PC4SP1,2	.29	0.15
1986	<3	PC4SP1,2		0.14
1987	<3	PC4SP1,2	.14	0.20
1988	<3	PC4SP1,2	.165	0.27
1989	<3	PC4SP1,2		0.26
1990	25.3	PC4SP2	.729	0.60
1991	91.4	PC4SP2	1.68	1.41
1996	2.4	PC4SP1	.363	1.51

4. **PW:** Although the design report (Co77) for the PW high intensity beam does not present a CASIM (or other) calculation, it does state that the minimization of ground water activation requires that the radius of a cylindrical steel absorber equivalent to the actual target and beam absorber in the PW6 target area be equal to or greater than 213 cm, and that this conclusion is adhered to in the final architectural design. Based on this statement, and not on an actual CASIM calculation, the star density just beyond this radius can be estimated by use of Fig. VIII. 4 of Van Ginneken and Awschalom (Va75a), to be about 5×10^{-10} stars/cm³-p. The ³H concentration outside the enclosure is then 5.1×10^{-20} pCi/ml-p. The appropriate sampling locations are PW6SP1, PW6SP2, and PW6SP3. Table 9 compares the crudely estimated concentrations with the maximum sampled concentrations. The high value for 1986 probably represents a closed loop cooling water system leak (Ba87). At any rate, it represents a ³H concentration well below surface water discharge limits.

Table 9: Comparison of calculated and sampled maximum ^3H concentrations for PW.

YEAR	$C_i(\text{MAX})$ (pCi/ml)	LOCATION	PROTONS/YR ($\times 10^{17}$)	$C_i(\text{CALC})$ (pCi/ml)
1985	6.5	PW6SP2	.79	0.004
1986	728.4	PW6SP2		0.004
1987	14.6	PW6SP2	.45	0.006
1988	9.9	PW6SP2	.28	0.007
1989	3.6	PW6SP2		0.007
1990	3.8	PW6SP3	.21	0.007
1991	3.4	PW6SP3	.145	0.008
1996	10.5	PW6SP2	.231	0.008

It is clear that the sampled concentrations are considerably larger than those estimated based on the number of protons incident on target. However, it should be emphasized again that the "calculated" concentrations do not represent a complete CASIM calculation based on the geometry of the beam absorber and target, but are only very crude estimates.

E872, which is currently (since 1996) running in the PW beam line, is targeting in the upstream end of PW8. A calculation by Freeman (Fr95) gives the star density underneath this area as 4.2×10^{-8} stars/cm³-p, or a ^3H concentration in the water in the ground of 4.3×10^{-18} pCi/ml-p. With 2.31×10^{16} protons incident to PW in 1996, the maximum ^3H concentration could be 0.1 pCi/ml below the enclosure, if all of that beam were actually targeted in PW8. More likely, however, most of this beam was incident on the beam absorber in PW5 during this running period. No sampling has been done in any PW8 sumps as yet.

C. Meson Area

1. **M01 (Meshall):** This enclosure was the Meson Area targeting enclosure in the pre-Tevatron era, and it includes a bathtub surrounding protected soil. It is about 400 m upstream of the Meson Detector Building which is now used for the targeting of all Meson Area beams. No Fermilab TMs, FNs or RP Notes have been located that document any calculation of the old M01 targetry as regards soil activation (nor, for that matter, any radiation safety concern), although there is some description of the components that make up the target box (see, e.g., Or71). From conversations with S. Baker (Ba97), there are 2 feet more steel on the top of this target box and 1 foot more on the other three sides than for the similar targeting configuration in Neuhall (in NC). Water sampling locations are M01SP2, M01SP3, and M02SP2. The maximum ^3H concentrations observed between 1985 and 1996 was 124 pCi/ml, in 1986, measured at M01SP3, presumably from the bathtub region. Although a large number of protons with a maximum energy of 400 GeV were targeted at this location

from 1979 to 1982, documentation of the water sample results is not easily obtainable, as they exist mostly in handwritten notebooks.

In 1988 sampling holes were bored into the Meson Area berm near the M01 targeting area. For all soil samples, the ^3H concentrations were less than the detection limit of 0.2 pCi/ml (Co90).

2. **ME:** In the extensive documentation (see, e.g., Co82b, incl. all attachments) associated with radiation safety considerations in the operation of this beam line in the Tevatron era, there is practically no discussion of possible groundwater activation that may arise from targeting in the SM12 magnet in the Meson Detector Building. In a draft memo by Cossairt (Co82c) contour plots from a CASIM run are presented but mainly in connection with shielding within the building and outside areas. It is possible, however, to read the maximum star density at the radius associated with the extent of the steel magnet and targetry. Taking $S_{\text{max}} = 7 \times 10^{-10}$ from the calculation in the vertical plane, one gets a ^3H concentration in the water in the ground of 7.3×10^{-20} pCi/ml-p. There are no sampling sumps or retention pits that are routinely monitored in the Meson Detector Building areas. In 1985, 1.73×10^{17} protons were targeted at ME. Thus, the maximum calculated ^3H concentration outside of the enclosure is estimated to be 0.01 pCi/ml. It is noted that the Meson Detector Building is protected from rainwater by a roof so that the quantity of water available for leaching ^3H from the soil is likely to be low.

3. **MP/MC/MW:** The three target piles for these beams in the Meson Detector Building are close to each other and very similar in design. Cossairt (Co83) modeled the MW target pile as representative. From the contour plots the maximum star density directly below the pile is 1×10^{-8} stars/cm³-p. This leads to an ^3H concentration in the water in the ground of 1.0×10^{-18} pCi/ml-p. In the year 1990, with 3×10^{17} protons (MW), 0.21×10^{17} protons (MC), and 1.8×10^{17} protons (MP) for a total of 5×10^{17} protons on target, the ^3H concentration could be 0.5 pCi/ml total from all beam lines. Again, it is emphasized that the roof over the building keeps rainwater away from the ground so that to some extent water is unavailable for leaching, and moving this ^3H into the aquifer. As mentioned above, no routine monitoring of water is done in the vicinity of the Meson Detector Building.

D. Accelerator Area

1. **Switchyard Dump:** Soil activation from the switchyard dump was discussed in a memo from Yurista to Childress (Yu85). Apparently 96-98% of the stars in the unprotected soil are produced in the area directly downstream of this location, rather than below (which is protected by underdrains) because the dump is quite short. It was actually built for 200 GeV beams. Recommendations for improvement to accommodate higher intensity beams were proposed, but apparently no changes were made. No star density contours are shown so that an estimate of S_{max} could not be obtained based on this memo. However, more recently Leveling (Le97) redid the calculation. The maximum star density in the unprotected soil below the dump is

about 8×10^{-9} stars/cm³-p, which leads to an ³H concentration of 8.1×10^{-19} pCi/ml-p. However, the star density in the unprotected soil directly downstream is a factor of about 100 times larger. It is not known how many protons have been aborted at this location. The sumps that are monitored are G1 and g1. Since 1985, the maximum ³H concentration observed was 9.4 pCi/ml. In 1987, a boring hole was dug in the vicinity. No radioactivity was seen in any of the soil samples (Le97).

2. **Linac Dump:** There are actually two locations in the Linac area at which beam is aborted. The one that receives the most beam is Dump # 2. An early calculation (Aw70) that utilized radionuclide production values in soil at 200 MeV given by Gabriel (Ga70), along with a simplified model to estimate the ³H concentration in the aquifer, concluded that "the beam dumps are grossly overdesigned from the point of view of contamination of underground waters leaving the site." A more recent calculation (in 1989) (Le97) based again on the 200 MeV radionuclide production rates in soil given by Gabriel (Ga70) gave a value of ³H concentration in soil outside of the region of 3.7×10^{-12} atoms/cm³(of soil) per proton/sec, or 3.18×10^{-18} pCi/cm³(soil) per proton/year. This value translates to 4.7×10^{-18} pCi/ml-p in the water in the ground per year. In 1993, the Linac was upgraded to 400 MeV. If the calculated ³H concentrations scale linearly then the above value could be doubled; that is, the ³H concentration would be 9.4×10^{-18} pCi/ml-p.

The water sampling locations are the same as for the whole Booster complex, sumps S1, S12, and T3. Since 1990, the maximum sampled ³H concentration in any one of these sumps was only 1.7 pCi/ml. During the Linac upgrade period, a number of soil samples were taken from holes drilled into the berm above the dump (Le97). No core samples, even those taken from nearby holes, showed ³H concentrations greater than 0.3 pCi/ml. It is not possible to compare with the above calculation since the number of protons actually incident at Dump # 2 is not known.

3. **Booster:** There are three beam absorber locations in the Booster area. For the 8 GeV dump at the AP4 line CASIM calculations were done by Yurista (Yu84a), but the star density contours associated with the soil activation calculations are not shown; only total stars per protons in given volumes of soil are presented. The 8 GeV proton dump in the by-pass line around the AP target station was also modeled by Yurista (Yu84b), as was the so-called Long 13 8-GeV dump (Yu83). Again, no star density contours are presented in either case. All of these calculations were performed in order to derive appropriate annual beam intensity limits based on the old SRWM. No ³H concentrations, based on the Concentration Model, can be derived. As mentioned above, however, the Booster area sumps S1, S12, and T3 have consistently shown little or no ³H concentration values above the detection limits of the analyses.

4. **D0:** Baker (Ba85) presented results of calculations and measurements at the Main Ring abort, which was located within the accelerator ring in the D0 straight section, and used between 1972 and 1982. The total number of protons aborted at this target was 1.8×10^{18} . As mentioned above (in Sect. II), Cu and Al tags inside the tunnel

were used to periodically monitor for soil activation. In addition, a soil boring was made in 1973 very close to the ring enclosure, and then later, in 1983, at a location about 1 m further away. Analyses of the soil samples revealed small concentrations of ^3H , but no evidence of leaching and subsequent movement of any radionuclide toward the aquifer. Comparison with a CASIM calculation (see Ba85) gave agreement with ^3H concentrations in soil (in pCi/g) to within a factor of two.

5. **AP0:** The latest and most complete calculation is by Marshall and Vaziri (Ma97). It includes a model of the geometry compiled from drawings of shielding, target assembly, lithium lens and pulsed magnet, conversations with appropriate scientists, actual measurements, and numerous old reports (see Ma97 for complete references). The maximum ^3H concentration in the soil near this location when converted into a concentration in the water in the ground compares well with concentrations in the water samples from the AP0 Prevault sump. This report is currently being revised to include estimated final ^3H concentrations in the aquifer as determined by the Concentration Model (Ma93, Co94).

6. **C0:** An extensive study of the Tevatron abort at C0 is currently in progress (Va97). ^3H concentrations based on star densities from a CASIM calculation will be compared to water samples from appropriate sumps in a manner similar to the recent study at AP0 (Ma97). References to appropriate previous reports concerning soil activation at the C0 abort will be included.

IV. Summary

At those sources for which calculations of ^3H concentrations adjacent to the targeting enclosures could be performed, the calculated values based on CASIM and the Concentration Model are either the same within factors of two or three, or systematically smaller than those sampled from sumps and retention pit water. Some of the reasons for sampled concentrations larger than those calculated are discussed in the appropriate sections of the report. They include the possibility of spills of closed loop cooling water systems as well as contributions to sumps and retention pits from adjacent target locations. Further, in the case of NC, the monitoring location showing the largest concentrations (N01RP2) samples activity from an area that was assumed to be a protected region (bathtub) so that soil activity would not in any event move down to the aquifer, but instead be collected in sump water. It should furthermore be recalled that the Concentration Model, as it has been used in this report, does not include the long term build up to saturation of soil activity that is a part of the model when used in its normal application.

For many of the other sources for which calculations were either not available, or from which ^3H concentrations could not be derived, results from sumps or retention pits all indicate measured values less than the surface water limit. Furthermore, independent analyses from soil boring samples verify the monitored values, and further suggest that there is little evidence of ^3H or any other radionuclide moving down to the aquifer at concentrations approaching the ground water limit.

V. References

- Aw70 M. Awschalom, *Linac Shielding: Expected Beam Losses, Design Criteria, Tolerable Beam Losses, Radioactivation and Remanent Exposure Rate, Dose Rate to Beam-Loss Monitors*, Fermilab Report TM-236, Fermilab, Batavia, IL (1970).
- Aw72 M. Awschalom, *Calculation of the Radionuclide Production in the Surroundings of the NAL Neutrino Laboratory*, Fermilab Report TM-292A, Fermilab, Batavia, IL (1972).
- Aw76 M. Awschalom, S. Baker, C. Moore, and A. Van Ginneken, *Measurements and Calculations of Cascades Produced by 300 GeV Protons Incident on a Target Inside a Magnet*, Nuclear Instr. and Meth. 138, 526 (1976).
- Ba75 S. I. Baker, *Soil Activation Measurements at Fermilab*, Proceedings of the Third Environmental Protection Conference, Chicago, IL, Sept. 23-26, 1975, Conference Report CONF-75096, ERDA-92, Vol. 1, p.329 (1975).
- Ba76 S. I. Baker, *Soil Activation Under the P-East Target Box*, Radiation Physics Note RP-12, Fermilab, Batavia, IL (1976).
- Ba85 S. I. Baker, *Fermilab Soil Activation Experience*, Proceedings of Fifth DOE Environmental Protection Information Meeting, Albuquerque, NM, Nov. 6-8, 1984, DOE Conference Report, CONF-841187, Vol. 2, p. 673 (1985).
- Ba87 S. I. Baker, *Site Environmental Report for 1986*, Fermilab Report 87/58, Fermilab, Batavia, IL, (1987).
- Ba97 S. I. Baker, Private Communication (1997).
- Bu83a S. Butala and A. Malensek, *Soil Activation*, Fermilab Memorandum to Tevatron Muon Line File (1/11/83).
- Bu83b S. Butala, *Comparison of Radiation Shields, Wide Band vs. Muhall*, Fermilab Memorandum to K. Stanfield (6/8/83).
- Co77 B. Cox, et al, *Design Report*, P-West High Intensity Secondary Beam Area, Fermilab, Batavia, IL (1977).
- Co79 J. D. Cossairt, *Review of the Shielding Requirements of the E-497 Target Magnet*, Fermilab Report TM-911, Fermilab, Batavia, IL (1979).
- Co80 J. D. Cossairt, *Radiation Safety Review of the Modified Enclosure 103*, Fermilab Report TM-976, Fermilab, Batavia, IL (1980).
- Co82a J. Couch, *Evaluation of Beam Dump Proposal for Front Hall*, Fermilab Memorandum to Stefanski/Stutte (4/6/82).
- Co82b L. Coulson, *Radiation Safety Review of E605*, Fermilab Memorandum to A.L. Reed (4/19/82).
- Co82c J. D. Cossairt, *Evaluation of Shielding of SM12 Magnet*, Fermilab Draft Memorandum to File (3/17/82).
- Co83 J. D. Cossairt, *Shielding of Tevatron Meson Laboratory Target Piles-M-West, M-Center, M-Polarized*, Fermilab Report TM-1235, Fermilab, Batavia, IL (1983).
- Co85 J. D. Cossairt, S. W. Butala, and M. A. Gerardi, *Absorbed Dose Measurements at an 800 GeV Proton Accelerator: Comparison with Monte Carlo Calculations*, Nucl. Instr. and Meth. A238, 504 (1985).

- Co90 J. D. Cossairt and D. W. Grobe, *Summary of Subsurface Exploration Near Neutrino and Meson Target Areas*, Environmental Protection Note EP-2, Fermilab, Batavia, IL (1990).
- Co94 J. D. Cossairt, *Use of a Concentration-Based Model for Calculating the Radioactivation of Soil and Groundwater at Fermilab*, Environmental Protection Note EP-8, Fermilab, Batavia, IL (1994).
- Fr92 W. Freeman, *PC4SP2 Tritium Release Update*, Internal Fermilab E-Mail Message to Cossairt, (3/26/92).
- Fr95 W. Freeman, *Groundwater Activation Calculations for E872*, Fermilab Report TM-1944, Fermilab, Batavia, IL (1995).
- Ga70 T. A. Gabriel, *Calculation of the Long-Lived Induced Activity in Soil Produced by 200 MeV Protons*, ORNL Report TM-2848, Oak Ridge National Lab, Oak Ridge, TN (1970).
- Ge83 M. Gerardi, *Beamline Shielding from PE-4 through the Wide Band Beam Experimental Hall-PB6*, Fermilab Memorandum to J. Butler (11/10/83).
- Go78 P. J. Gollon, *Soil Activation Calculations for the Anti-Proton Target Area*, Fermilab Report TM-816, Fermilab, Batavia, IL (1978).
- Ko91 G. Koizumi and G. Gutierrez, *NW3 Ground Water Activation*, Fermilab Memorandum to P. Garbincius (9/10/91).
- Le97 A. Leveling, Accelerator Dump Files, Logbooks, etc., and Private Communication (1997).
- Ma93 A. J. Malensek, A. A. Wehmann, A. J. Elwyn, K. J. Moss, and P. M. Kesich, *Groundwater Migration of Radionuclides at Fermilab*, Fermilab Report TM-1851, Fermilab, Batavia, IL (1993).
- Ma97 E. Marshall and K. Vaziri, *Calculation of Maximal Tritium Concentrations in Soil Near AP0*, Environmental Protection Note EP-7, Fermilab, Batavia, IL (1997).
- Mi96 W. Miller, *Groundwater Activation Calculations for E-831 Targeting in PE4*, Fermilab Memorandum to PBEast Radiation Safety File (3/4/96).
- Mo77 C. Moore and S. I. Baker, *E100 Soil Studies*, Radiation Physics Note RP-17, Fermilab, Batavia, IL (1977).
- Or71 J. R. Orr and A. L. Read, *Preliminary Design Report*, Meson Laboratory, Fermilab, Batavia, IL (1971).
- Va75a A. Van Ginneken and M. Awschalom, *Hadronic Cascades, Shielding, Energy Deposition*, High Energy Particle Interactions in Large Targets, Vol. 1, Fermilab, Batavia, IL. (1975).
- Va75b A. Van Ginneken, *CASIM- Program to Simulate Transport of Hadronic Cascades in Bulk Matter*, Fermilab Report FN-272, Fermilab, Batavia, IL (1975).
- Va97 K. Vaziri and E. Marshall, Private Communication (1997).
- Wc93 Woodward-Clyde Consultants, Summary of Radionuclide Transport Modeling for Ground Water at the Fermi National Accelerator Laboratory, Batavia, Illinois, Project 92C3073, Chicago, IL (1993).
- Yu83 P. M. Yurista, *Booster 8 GeV Dump Soil Activation*, Fermilab Memorandum to File (6/14/83).

- Yu84a P. M. Yurista, *8 GeV Target Station Radiation Shielding*, PBAR Note 359, Fermilab, Batavia, IL (1984).
- Yu84b P. M. Yurista, *Antiproton Target Vault By Pass Line Beam Stop*, PBAR Note 400, Fermilab, Batavia, IL (1984).
- Yu85 P. M. Yurista, *Soil Activation from the Switchyard Dump*, Fermilab Memorandum to S. Childress (undated, but probably 1985).
- Zi96 R. Zimmermann, *Ground Water for PCenter (E-781)* Fermilab Memorandum to PCenter Rad Safety File (3/1/96).